DEPARTMENT OF NATIONAL DEFENCE
CANADA

OPERATIONAL RESEARCH DIVISION

DIRECTORATE OF OPERATIONAL RESEARCH (JOINT & LAND)

DOR (J&L) RESEARCH NOTE RN 2000/08

A METHODOLOGY FOR ASSESSING THE EFFECTS OF AN ARMOUR-DEFEATING PROJECTILE ON AN ARMOURED VEHICLE

by

M.K. Ormrod

D.C Wilkinson (under contract)

JUNE 2000

OTTAWA, CANADA

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ABSTRACT

This paper proposes an operational research methodology for determining the effects on an armoured vehicle, its crew and passengers of an armour-piercing projectile which has defeated the protection of the vehicle. The process involves determining the proportion of the internal volume occupied by key spaces. The effect on the vehicle is estimated for a range of damage to each space. The probability of damage to the vehicle is determined by the proportion of the volume and the likelihood of damage represented by the spaces that the projectile penetrates. Application of the process to representative vehicles demonstrates that a consistency exists for similar types of vehicles.

RÉSUMÉ

Ce document propose une méthode de recherche opérationnelle afin de déterminer les effets sur le véhicule blindé, son équipage et ses passagers face aux obus perforants ayant détruit la protection du véhicule. La méthode consiste à déterminer la proportion du volume interne occupé par les espaces critiques. L'effet sur le véhicule est estimé en fonction de l'ampleur du dommage en chacun des espaces. La probabilité du dommage causé au véhicule est déterminée par la proportion du volume et la vraisemblance du dommage représentée par les espaces pénétrés par l'obus. L'application de cette méthode sur des véhicules types démontre qu'il existe une similitude pour des modèles de véhicules semblables.

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LIST OF ABBREVIATIONS

ACV	Armoured Combat Vehicle
AFV	Armoured Fighting Vehicle
APC	Armoured Personnel Carrier
CE	Chemical Energy
CIS	Commonwealth of Independent States
CSS	Combat Service Support
Fdeg	Firepower degradation
F kill	Firepower kill
HEAT	High Explosive Anti-Tank
HEP	High Explosive Plastic
HESH	High Explosive Squash Head
IFV	Infantry Fighting Vehicle
KE	Kinetic Energy
K kill	Catastrophic kill
MBT	Main Battle Tank
Mdeg	Mobility degradation
MF kill	Mobility and Firepower kill
MKC	Multiple Kill Category
M kill	Mobility kill
P cas	Passenger casualties
PH	Probability of Hit
PK	Probability of Kill
SP	Self Propelled

A METHODOLOGY FOR ASSESSING THE EFFECTS OF AN ARMOUR-DEFEATING PROJECTILE ON AN ARMOURED VEHICLE

I. INTRODUCTION

BACKGROUND

1. Simulating combat will always remain an over simplification of a complex process. As simulations become more sophisticated, their value only increases if the outcomes can be supported by reference to field trials, battle damage assessments and respected professional judgements. The effects of direct fire on armoured vehicles is one area where some confidence can be given to the determination of the defeat of the armour by the projectile. What remains difficult to predict is what actually happens after the armour is penetrated.

2. Anti-armour projectiles fall into two categories, kinetic energy (KE) projectiles and chemical energy (CE) projectiles. The KE projectiles carry no explosives. They defeat the target by punching through the armour with a dense penetrator. The penetrator may fracture and together with armour fragments, may splatter in a cone-shaped pattern along the line of flight. Components of the target may be broken away and become secondary projectiles within the vehicle. CE projectiles are different in that they contain a shaped-charge warhead that produces a jet of gas and molten metal that burns through the target. The most common CE projectiles are normally high explosive anti-tank (HEAT). HEAT causes considerable damage to the interior of the target from the explosion of the shaped charge and the plasma jet. A less frequently encountered CE round is high explosive squash head (HESH), sometimes called high explosive plastic (HEP). This round does not penetrate the armour but defeats it by detonating on the outside of the vehicle and causing a shock wave that forces fragments of armour to break off inside the vehicle. These fragments, called spall, are projected at high velocity around the inside of the vehicle. The secondary effects of KE and CE projectiles that have defeated the armour protection are not as predictable as the mechanics of the initial defeat of the armour itself.

3. Many simulations of battle presume that a vehicle is either killed or is unaffected when its armour is penetrated. For research or training, this may be all that is required for scenarios of short duration. If the objective is to involve combat service support (CSS) aspects, or if the scenario being modelled is of a longer duration, then some benefit could be gained by a more defined effect. The difficulty in defining this effect is predicting the result of armour penetration and doing so in a timely manner. It is most unlikely that this will ever be accurately simulated because of the number of factors involved and the time that would be required to process them. In a real-time simulation with a large number of combatants, this may never be possible. A simpler methodology is required.

4. In the Directorate of Operational Research (Joint & Land) (DOR(J&L)) the primary wargaming tool is the Janus simulation. For a number of years, this simulation has been evolving into one that considers multiple kill categories. Version 7.06D includes a rudimentary technique as a 'first cut' determination of kill type. For the multiple kill effect to be supportable by the training and research communities it must be seen to be the result of a logical process.

AIM

5. The aim of this Research Note is to describe a technique for determining the category of damage to a target vehicle resulting from the defeat of its armour protection.

II. METHODOLOGY

6. The process described in this document allows one to predict the effects on an armoured vehicle, its crew, and passengers of a projectile which has defeated the armour protection of the vehicle. As mentioned previously, the wide range of possible behind armour effects depends on so many variables that they defy, except in the grossest form, accurate prediction. For the methodology described in this Research Note, the process has been greatly simplified It ascribes probabilities to the various outcomes of the defeat of the armour based on the characteristics of individual vehicles and their internal spaces. The methodology chosen here produces believable results that are the product of a rational, impartial process.

7. Armoured vehicles may be divided into a finite number of spaces that together, total the internal volume of the vehicle. For the purposes of this method, a vehicle is divided into seven types of spaces as follows:

a. Crew Space. The total volume that is, or could be, occupied by crew members;

b. Passenger Space. The total volume that is, or could be, occupied by passengers;

c. Drive Train Space. The total volume occupied by the engine, cooling system, batteries, transmission, final drives, wheels suspension and tracks. Note that some of these components are mounted outside the armour envelope of the hull;

d. Ammunition Space. The total volume occupied by ammunition when the vehicle is fully bombed up;

e. Fuel Space. The total volume occupied by fuel when the vehicle is fully fueled. Some of this fuel may be carried outside the armour envelope;

f. Equipment Space. The total volume occupied by the data buses, instruments, communications equipment, fire suppression devices and all

other equipment important to the effective functioning of the vehicle, but not directly related to weapon systems; and

g. Weapon & Sensor Space. The total volume occupied by the main and secondary armament, fire control equipment, range finders, auto loaders, target acquisition and engagement optics and electro-optics, and the stabilization and turret traverse mechanisms.

8. Classification of Damage. A projectile, which defeats the armour of the vehicle and enters a space indicated above, is deemed to have one of three effects which cover the full range of possible outcomes:

a. Destruction. Severe interference with, or total destruction of, the key item or items occupying the space resulting in a loss of function from that space;

b. Damage. Disruption or partial destruction of the items occupying the space resulting in a degradation of the function provided from that space; or

c. No Effect. No impact on items within the space.

9. Weapons Effects on Spaces. For each space a definition of the three effects must be determined. Obviously the "No Effect" situation relates to a penetration of the space with no direct impact on any essential component. The remaining, more serious effects are subjective and, at present, are defined as follows:

a. Crew Space:

(1) Destruction. 50% or more of the crew dead or seriously wounded;

(2) Damage. One crew member dead or seriously wounded.

b. Passenger Space:

(1) Destruction. 50% or more passengers dead or seriously wounded;

(2) Damage. Two passengers dead or seriously wounded.

c. Drive Train Space:

(1) Destruction. Major component damaged beyond local repair;

(2) Damage. Major component damaged but repairable.

d. Ammunition Space:

(1) Destruction. Ammunition detonates sympathetically, resulting in destruction of the vehicle, crew and passengers;

(2) Damage. A portion of the ammunition rendered unuseable.

e. Fuel Space:

(1) Destruction. Fuel ignites uncontrollably resulting in the destruction of the vehicle;

(2) Damage. Fuel storage ruptured resulting in loss of fuel without uncontrollable fire.

f. Equipment Space:

(1) Destruction. Vehicle unable to continue mission due to loss of a critical piece of equipment;

(2) Damage. Vehicle may continue with mission but is functionally degraded.

g. Weapon & Sensor Space:

(1) Destruction. Weapons or component critical to the continued functioning of the weapons damaged beyond repair;

(2) Damage. Weapons are able to be used but are reduced in effectiveness because of damage to key components of the fire control system.

10. Actions Resulting from Damage. When a projectile defeats the armour of the vehicle, a series of actions take place based on the severity of damage to the affected spaces. It is possible to predict a likely outcome of the attack and a crew response dependent on the space compromised. The following list indicates the most significant

actions/responses in chronological order. It is not intended to include every response, only those which may be significant to a simulation such as Janus.

a. Crew Space:

(1) Destruction. Vehicle halts, surviving crew evacuate and seek shelter.

(2) Damage.

(a) Driver casualty. Vehicle halts, pops smoke, waits while driver is replaced, moves to cover, waits while driver is evacuated, and then returns to action with firing degraded.

(b) Gunner, commander or loader casualty. Vehicle stops firing, pops smoke, moves to cover, waits while the casualty is evacuated, and then returns to action with firing degraded.

Note Any crew casualty will result in a degradation in the ability to acquire and engage targets. If one of the turret crew becomes a casualty or must replace a driver who has become a casualty, then either the primary gunner has been replaced by another crew member or another turret position is vacant. The result is that some function related to target acquisition or firing has been degraded.

b. Passenger Space:

(1) Destruction. Vehicle pops smoke, seeks cover, and waits for medical support while crew and surviving passengers apply first aid.

(2) Damage. Vehicle may seek cover to evacuate passengers killed or wounded, or may continue while surviving passengers apply first aid.

c. Drive Train Space:

(1) Destruction. Vehicle halts, pops smoke, and then is either abandoned or returns to action unable to move. Vehicle is recoverable.

(2) Damage. Vehicle halts, pops smoke, waits while damage is assessed and possibly repaired, and then returns to action with mobility degraded. Full mobility could be restored given time and the appropriate repair crew.

d. Ammunition Space:

(1) Destruction. Vehicle is destroyed, and crew is killed.

(2) Damage. Vehicle halts, pops smoke, waits while damage is assessed, and then either returns to action or seeks first echelon support depending on the amount of ammunition still available.

e. Fuel Space:

(1) Destruction. Vehicle and crew are destroyed by fire.

(2) Damage. Vehicle pops smoke, seeks cover, waits while damage is assessed, and then either returns to action or seeks first echelon support depending on the amount of fuel still available.

f. Equipment Space:

(1) Destruction. Vehicle halts, pops smoke, seeks cover, waits while damage is assessed, and then either returns to action or seeks first echelon support depending on the equipment destroyed.

(2) Damage. Vehicle halts, pops smoke, seeks cover, waits while damage is assessed and possibly repaired, and then either returns to action or seeks first echelon support depending on the equipment damaged.

g. Weapon & Sensor Space:

(1) Destruction. Vehicle pops smoke, seeks cover, waits while damage is assessed; and then either returns to action with no weapon system or target acquisition available or seeks first echelon support.

(2) Damage. Vehicle pops smoke, seeks cover, waits while damage is assessed and possibly repaired, and then either returns to action with firepower degraded or seeks first echelon support.

11. Simulation of the Results of Damage. It is now possible to determine the likely effect on a vehicle for different levels of damage to the various enclosed spaces and the resulting events. It is necessary to put this in terms applicable to a simulation. There is an advantage to simplifying and combining actions, provided realism can be maintained. Reducing the requirement for an interactor to become involved in a predictable series of events should also be an objective. It can be seen that the effects on the vehicle fall into mobility (M), firepower (F) and catastrophic (K) kills, and what can be termed mobility and firepower degradations (Mdeg, Fdeg). These directly affect the status and capability of the system. In addition, for passenger carrying vehicles, P kill and P cas define levels of casualties resulting from penetration of the passenger compartment. The remaining effects represent actions performed by crew members as a result of the damage. Definitions of the vehicle status are as follows:

a. K kill. Complete destruction of the vehicle, crew, and passengers;

b. M kill. This result follows from injury or death to half or more of the crew, or the vehicle is damaged beyond local repair and is unable to move under its own power. The weapon systems and sensors remain functional, and the vehicle may be recovered;

c. F kill. The weapon system and associated sensors are non-functional and beyond local repair. The vehicle remains mobile;

d. Mdeg. After a time delay for crew repair, the vehicle may move but at a reduced speed (50%). The vehicle may be repaired by the appropriate repair team and returned to full serviceability;

e. Fdeg. This form of degradation must simulate the effect of damage to the weapon system as well as the use of emergency or alternate means of engaging targets because of injury or death of a turret crew member. The vehicle may continue to move, but targets are engaged less effectively. The vehicle may be returned to full serviceability by the appropriate repair team. It would be assumed that a replacement crew member would be provided during the time of repair;

f. P kill. Half the passengers are dead or wounded. The remaining passengers provide emergency first aid. The vehicle does not continue with the mission, but remains combat effective. The vehicle could be reloaded with passengers but not from the original section;

g. P cas. Two passengers are dead or wounded. The vehicle continues with the mission; and

h. No Effect. The projectile does not impact with any significant object within the space. This outcome is the least likely, but must be considered since all the internal spaces include empty volume.

12. The table below summarizes the actions and status resulting from the various degrees of damage to a specific space.

TABLE I
SUMMARY OF ACTION AND VEHICLE STATUS

Vehicle Space	Degree of Damage	Simulated Actions	Vehicle Status
Crew	Destruction	Vehicle halts, pops smoke, surviving crew evacuate	M kill
	Damage	Vehicle halts, pops smoke, waits, returns to action	Fdeg
Passenger	Destruction	Vehicle halts, pops smoke, moves to cover, waits for medical assistance	P kill
	Damage	Two passengers killed or seriously wounded	P cas
Drive Train	Destruction	Vehicle halts, pops smoke, firepower unaffected, may be recovered by appropriate vehicle	M kill
	Damage	Vehicle halts, pops smoke, waits, return to action	Mdeg
Ammo	Destruction	Vehicle destroyed, all passengers and crew killed	K kill
	Damage	Available ammo reduced by 25%	Fdeg
Fuel	Destruction	Vehicle destroyed, 50% of passengers and crew killed	K kill
	Damage	Vehicle pops smoke, seeks cover, waits, returns to action, fuel supply reduced by 50%	Mdeg
Equipment	Destruction	Vehicle halts, pops smoke, firepower unaffected	M kill
	Damage	Vehicle halts, pops smoke, waits, may be repaired by appropriate vehicle and returned to action	Mdeg
Weapon & Sensor	Destruction	Vehicle pops smoke, seeks cover, waits	F kill
	Damage	Vehicle pops smoke, seeks cover, waits, return to action	Fdeg

CRITERIA FOR CLASSIFICATION OF DAMAGE

13. To maintain a level of consistency in the assignment of damage classification probabilities, the proposed methodology must minimize the subjective nature of the assessment. Unless experimental data can be acquired, there will always be an element of opinion involved in the assigning of probabilities. These predictions must be carefully examined should empirical data become available. For this paper, military judgement was used. It is recommended that a panel of experts review these probabilities and a consensus be sought to modify or confirm the assigned values. The probabilities here are based on the possible effects of both kinetic energy (KE) and chemical energy (CE) rounds and are neither meant to be the worst case, nor the best case. A sound knowledge of the vehicles under investigation is required before values can be selected.

14. Crew Space. For the various crew sizes the range of values is determined by layout and proximity of the crew members and the additional space included in the assigned crew spaces. Bear in mind that empty space is included and in vehicles with spacious crew positions the probability of "No Effect" increases.

TABLE II
CREW SPACE PROBABILITIES OF DAMAGE

Number of Crew	Destruction	Damage	No Effect
One or Two	.45	.45	.10
Three	.30 - .35	.55 - .60	.05 - .10
Four	.40 - .45	.45 - .50	.05 - .15

15. Passenger Space. Passenger carrying armoured vehicles normally have extremely confined accommodation. The assessed probabilities must be assigned with knowledge of the number of passengers carried and the layout of the passenger compartment.

TABLE III
PASSENGER SPACE PROBABILITIES OF DAMAGE

Destruction	Damage	No Effect
.30 - .45	.45 - .60	.10

16. Drive Train Space. A single set of probabilities has been assigned for tracked vehicles. Wheeled armoured vehicles with more than four wheels can have redundant wheel stations. In addition most wheeled armoured vehicles now have run-flat tires or central inflation systems.

TABLE IV
DRIVE-TRAIN SPACE PROBABILITIES OF DAMAGE

Drive Train Type	Destruction	Damage	No Effect
Tracked	.40	.50	.10
Wheeled (4)	.35	.55	.10
Wheeled (6-8)	.25	.65	.10

17. Ammunition Space. In most vehicles, ammunition is stored in several locations in the fighting compartment. The effect of an armour defeating round on the ammunition spaces varies widely because of the natures of different ammunition and the design characteristics of the vehicles. The carrousel of the T-72 family is notorious for catastrophic explosions while the turret bustle storage of the M1 is designed to vent into the atmosphere and avoid destruction of the vehicle. Knowledge of the ammunition storage and battlefield performance (if any) is necessary in assigning probabilities.

TABLE V
AMMUNITION SPACE PROBABILITIES OF DAMAGE

Ammo Storage	Destruction	Damage	No Effect
Carrousel Autoloader	.85	.10	.05
Internal Unprotected	.75	.20	.05
Internal Protected	.70	.25	.05
Turret Blow-out Panels	.20	.75	.05

18. Fuel Space. Three sets of probabilities have been used to represent the three common fuel storage circumstances in armoured vehicles. For vehicles where the fuel storage is mainly within the armour envelope, a standard probability is used. For vehicles such as the Commonwealth of Independent States (CIS) family of MBTs where fuel is

mainly stored outside the armour, a reduced probability of destruction is assigned. The least common and most destructive situation is for gasoline powered vehicles.

TABLE VI
FUEL SPACE PROBABILITIES OF DAMAGE

Fuel Storage	Destruction	Damage	No Effect
Internal Diesel	.60	.30	.10
External Diesel	.40	.40	.20
Gasoline	.85	.10	.05

19. Equipment Space. The equipment space is located all over the vehicle and involves a number of communication and electrical systems. Most vehicles have redundant systems or manual back-ups to allow some sort of function at a reduced level. Because of the wide range of possibilities and unknowns, a standard set of probabilities is used.

TABLE VII
EQUIPMENT SPACE PROBABILITIES OF DAMAGE

Destruction	Damage	No Effect
.45	.45	.10

20. Weapon & Sensor. All modern armoured vehicles have redundant sensors and fire control equipment. In addition, procedures and techniques are practiced to allow for continued but degraded operations following damage. The complexity of main armament autoloaders in CIS vehicles increases the volume of the weapon space and the likelihood of destruction if the weapon space is penetrated. Two sets of probabilities are included, one for vehicles with auto-loaders and one without.

TABLE VIII
WEAPON & SENSOR SPACE PROBABILITIES OF DAMAGE

Weapon & Sensor	Destruction	Damage	No Effect
Manual Loading	.60	.30	.10
Autoloader	.75	.20	.05

DETERMINATION OF VEHICLE SPACES PENETRATED

21. Given that the entire internal volume of the vehicle is included in the seven designated spaces, initial penetration of the vehicle armour must include penetration of one of the spaces. Each space is the total of sub-spaces located at various places around the vehicle. Since the sub-spaces are distributed around the vehicle in what may be assumed to be a random fashion, it is assumed that the probability that any space is struck is a function of its percentage of the total internal volume.

22. The next step is to determine the proportions of the spaces in the vehicle. It was first presumed that a standard division of the internal volume could be used. Reference 1 includes the volumetric division of a typical battle tank and this was used for the initial development of this technique. Unfortunately, upon examination of the internal layouts of a number of vehicles it was found that there was considerable variance from the 'typical' numbers. Therefore, internal volumes had to be calculated from measurements taken from scale drawings of the vehicle being analyzed.

23. The definition of the Drive Train Space includes components such as tracks and wheels that are normally mounted outside the armour envelope. To account for these external components, the total internal volume is increased by 20% for tracked vehicles and 10% for wheeled vehicles. This additional volume is added to Drive Train Space. When measurements are made and the calculations done to determine the percent of the total volume, the results for the tank described in Reference 1 come out as follows:

a.	Crew Space	26.4%;
b.	Passenger Space	0%;
c.	Drive Train Space	38.4%;
d.	Ammunition Space	4.8%;
e.	Fuel Space	12%;
f.	Equipment Space	8%; and,
g.	Weapon & Sensor Space	10.4%.

24. With the division of the vehicle into spaces, the next step is to estimate the probability of each of the three degrees of damage occurring, given a projectile penetrates that space. Using the criteria for classification of damage, the table below represents a typical battle tank fielded in the 1970s. The probabilities were taken from Tables II–VIII.

TABLE IX
PROBABILITIES OF DAMAGE TO EACH MBT VEHICLE SPACE

SPACE	PROBABILITY				
	Destruction	Status	Damage	Status	No Effect
Crew	.40	M kill	.50	Fdeg	.10
Passenger	.00	P kill	.00	P cas	.00
Drive Train	.40	M kill	.50	Mdeg	.10
Ammunition	.70	K kill	.25	Fdeg	.05
Fuel	.60	K kill	.30	Mdeg	.10
Equipment	.45	M kill	.45	Mdeg	.10
Weapon & Sensor	.60	F kill	.30	Fdeg	.10

25. In Table I the simulation of the results of damage were defined. Now since the probability of a space being penetrated is presumed to be directly related to its proportion of the total vehicle volume, and the result of that penetration is estimated in the table above, the probability of the identified outcomes can be determined.

TABLE X
PROBABILITY OF OUTCOME GIVEN MBT SPACE PENETRATION

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	26.4	.40	M kill	.106	.50	Fdeg	.132	.10	.026
Passenger	0.0	.00	P kill	.000	.00	P cas	.000	.00	.000
Drive Train	38.4	.40	M kill	.154	.50	Mdeg	.192	.10	.038
Ammunition	4.8	.70	K kill	.034	.25	Fdeg	.012	.05	.000
Fuel	12.0	.60	K kill	.072	.30	Mdeg	.036	.10	.012
Equipment	8.0	.45	M kill	.036	.45	Mdeg	.036	.10	.001
Weapon & Sensor	10.4	.60	F kill	.062	.30	Fdeg	.031	.10	.001

26. If the status of damage is now summed for all spaces the probability of that type of damage is now determined for any single penetration of the vehicle. The results for the typical battle tank are shown below.

TABLE XI
PROBABILITY OF SINGLE SPACE DAMAGE -MBT

Damage Result	Probability
K kill	.106
M kill	.296
F kill	.062
Mdeg	.264
Fdeg	.175
No Effect	.097

27. Involvement of Additional Spaces. Given the nature of armour piercing ammunition, it is unlikely that defeat of the armour protection of a vehicle will result in damage to only one space. The behind armour effects are such that even if the assumption is made that the projectile will fly straight, at least one adjacent space is bound to be involved. An argument could be made to include a third or more spaces, but until data can confirm this, an assumption will be made that only two spaces will be involved. For the purposes of simulation, the effects of these penetrations will be additive. The diagram below of a front and side elevation of a main battle tank demonstrates that single space damage is unlikely.

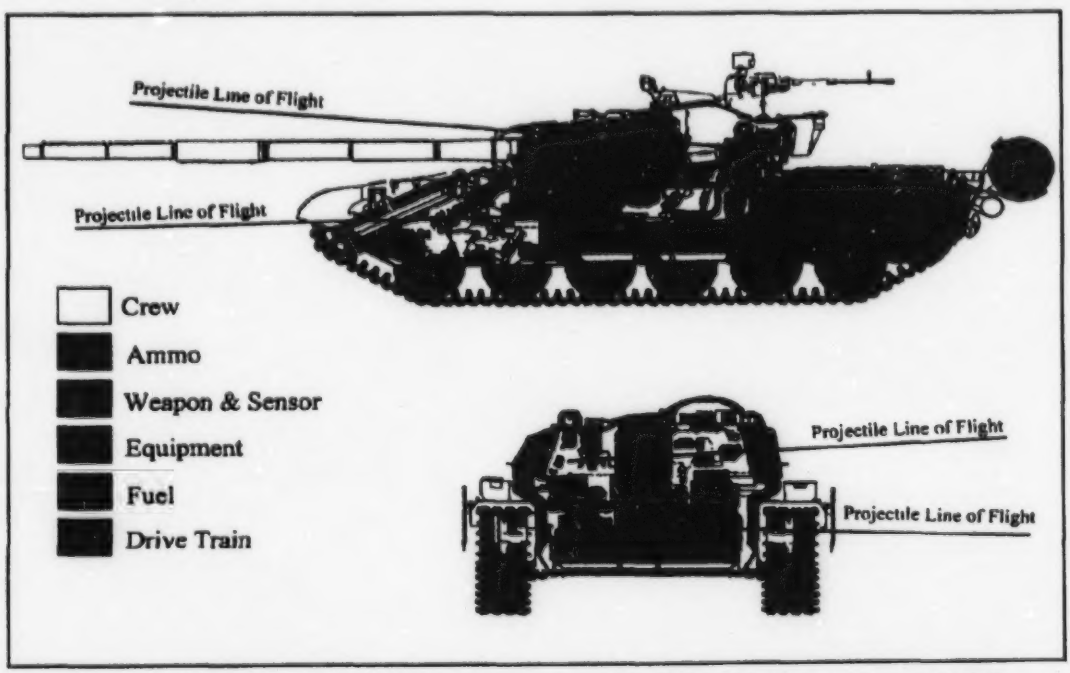

Figure 1: Involvement of Additional Spaces with Projectile Penetration of MBT

28. The same logic can be applied to determine the likelihood of damage occurring in an adjacent space. Therefore it is proposed that two random numbers be drawn for each armour penetration and the results summed. Assumptions must be made in doing thi. First, anything plus a K kill results in a K kill, and second, an M or F kill plus a similar degradation results in only the appropriate kill. Finally, two similar degradations are equivalent to a kill. The resulting damage matrix is shown below.

TABLE XII
DAMAGE MATRIX FOR TWO-SPACE INVOLVEMENT

		FIRST RANDOM NUMBER DRAW					
		K kill	**M kill**	**F kill**	**M deg**	**F deg**	**No effect**
SECOND RANDOM NUMBER DRAW	**K kill**	K kill	K kill	K kill	K kill	K kill	K kill
	M kill	K kill	M kill	M&F kill	M kill	M kill Fdeg	M kill
	F kill	K kill	M&F kill	F kill	F kill Mdeg	F kill	F kill
	M deg	K kill	M kill	F kill Mdeg	M kill	M&F deg	M deg
	F deg	K kill	M kill Fdeg	F kill	M&F deg	F kill	F deg
	No effect	K kill	M kill	F kill	M deg	F deg	No effect

29. For simulation purposes the accompanying actions resulting from the damage effects listed in Table I may be simplified. In the case of Janus, it may be advisable to treat each vehicle not completely destroyed (K kill) in the same fashion. The vehicle halts, pops smoke (if possible), and if still mobile is placed in full defilade to represent movement to cover. After a specified time delay to represent crew assessment of damage and possible repair, the vehicle is allowed to rejoin the battle at its degraded state.

APPLICATION TO VEHICLES IN PARTIAL DEFILADE

30. Not all targets on the battlefield are fully exposed to the enemy. Commanders of Armoured Fighting Vehicles (AFVs) look for terrain cover to reduce the likelihood of being seen and engaged. AFVs that are static and ready to engage the enemy adopt what is termed partial defilade. Partial defilade is defined as a vehicle situated so that only the portion of the turret above the turret ring is exposed to an opposing vehicle. Janus considers targets being engaged as being either fully exposed or in partial defilade. For vehicles in partial defilade, an assumption is made that only turret spaces can be damaged by the projectile since only the turret is presented to the enemy. In reality, this may not always be the case because of fragmenting penetrators and secondary damage by spall, etc., but in general, it is much more likely that only turret spaces will be involved. The methodology followed for the fully exposed MBT is repeated below for the MBT in partial defilade. The turret volume is typically made up of only four spaces and their relative proportions are given here as estimates:

a. Crew Space 18%;

b. Ammunition Space 12%;

c. Equipment Space 17%; and

d. Weapon & Sensor Space 53%.

31. The weapon effects on the spaces and the actions resulting from the effects remain the same as for the entire vehicle. What changes are the proportions and the likelihood of damage resulting from penetration.

TABLE XIII

PROBABILITIES OF DAMAGE TO EACH TURRET SPACE

SPACE	PROBABILITY				
	Destruction	Status	Damage	Status	No Effect
Crew	.40	M kill	.50	Fdeg	.10
Ammunition	.75	K kill	.20	Fdeg	.05
Equipment	.45	M kill	.45	Mdeg	.10
Weapon & Sensor	.75	F kill	.20	Fdeg	.05

32. The likelihood of specific classes of damage can now be determined as follows:

TABLE XIV
PROBABILITY OF OUTCOME GIVEN TURRET SPACE PENETRATION

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	18	.40	M kill	.072	.50	Fdeg	.090	.10	.018
Ammunition	12	.75	K kill	.090	.20	Fdeg	.020	.05	.010
Equipment	17	.45	M kill	.077	.45	Mdeg	.077	.10	.016
Weapon & Sensor	53	.75	F kill	.397	.20	Fdeg	.106	.05	.027

33. Grouping of the classes of damage for a single penetration of a space from a single random number draw results in the following:

TABLE XV
PROBABILITY OF TURRET DAMAGE

Damage Result	Probability
K kill	.090
M kill	.149
F kill	.397
Mdeg	.077
Fdeg	.216
No Effect	.071

34. The same argument can be made for the involvement of a second space in the turret as was made for the vehicle as a whole. A second random draw with the same probabilities will result in the same damage matrix as shown in Table XII.

III. INFANTRY FIGHTING VEHICLE EXAMPLE

35. The methodology used for the MBTs can be used for other classes of vehicles but the internal spaces are of course different, as are the probabilities of damage. For the purposes of this paper, the BMP 1 was selected as an example of an infantry fighting vehicle (IFV). The internal spaces of a BMP-1 are shown in Figure 2 as well as evidence that damage to only one space is unlikely.

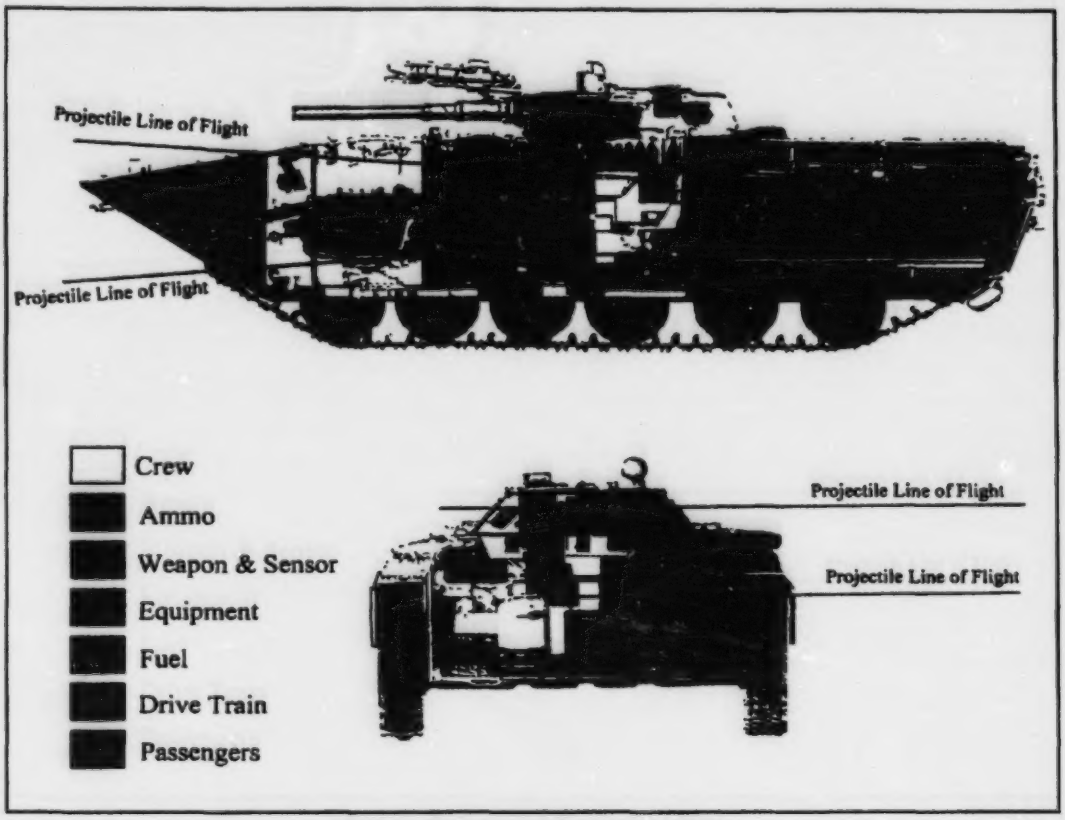

Figure 2: Internal Spaces of IFV

36. Measurements taken from a scale drawing of the vehicle result in the following spaces as a percentage of the enclosed volume. The volumes represent a fully exposed vehicle.

a.	Crew Space	10%;
b.	Passenger Space	27%;
c.	Drive Train Space	45%;

d. Ammunition Space 5%;

e. Fuel Space 4%;

f. Equipment Space 3%; and

g. Weapon & Sensor Space 6%.

37. The degree of damage given penetration of each space was estimated, as was the probability of that damage occurring based on knowledge of the internal layout of the vehicle and its construction.

TABLE XVI
PROBABILITIES OF DAMAGE TO EACH IFV SPACE

SPACE	PROBABILITY				
	Destruction	Status	Damage	Status	No Effect
Crew	.45	M kill	.45	Fdeg	.10
Passenger	.45	P kill	.45	P cas	.10
Drive Train	.40	M kill	.50	Mdeg	.10
Ammunition	.75	K kill	.20	Fdeg	.05
Fuel	.60	K kill	.30	Mdeg	.10
Equipment	.45	M kill	.45	Mdeg	.10
Weapon & Sensor	.75	F kill	.20	Fdeg	.05

38. In Table I the results of damage were defined. Now since the probability of a space being penetrated is directly related to its proportion of the total vehicle volume and the result of that penetration is estimated in the table above, the probability of the effect occurring can be determined.

TABLE XVII
PROBABILITY OF OUTCOME GIVEN IFV SPACE PENETRATION

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	10	.45	M kill	.045	.45	Fdeg	.045	.10	.010
Passenger	27	.45	P kill	.121	.45	P cas	.121	.10	.028
Drive Train	45	.40	M kill	.180	.50	Mdeg	.225	.10	.045
Ammunition	5	.75	K kill	.038	.20	Fdeg	.010	.05	.002
Fuel	4	.60	K kill	.024	.30	Mdeg	.012	.10	.004
Equipment	3	.45	M kill	.014	.45	Mdeg	.014	.10	.003
Weapon & Sensor	6	.75	F kill	.045	.20	Fdeg	.012	.05	.003

39. If the status of damage is now summed for all spaces the probability of that type of damage is now determined for any single penetration of the vehicle with a single random number draw. The results for the fully exposed IFV are shown below.

TABLE XVIII
PROBABILITY OF IFV DAMAGE

Damage Result	Probability
K kill	.062
M kill	.239
F kill	.045
Mdeg	.250
Fdeg	.067
P kill	.121
P cas	.121
No Effect	.095

40. The same argument for additional space involvement used for the tank is valid here. A second random number must be drawn to establish the damage to an adjoining space and the damage summed as shown in Table XIX.

TABLE XIX
DAMAGE MATRIX FOR IFV TWO-SPACE INVOLVEMENT

		FIRST RANDOM NUMBER DRAW							
		K kill	M kill	F kill	M deg	F deg	P kill	P cas	No effect
SECOND RANDOM NUMBER DRAW	K kill	K kill	K kill	K kill	K kill	K kill	K kill	K kill	K kill
	M kill	K kill	M kill	M&F kill	M kill	M kill Fdeg	M&P kill	M kill P cas	M kill
	F kill	K kill	M&F kill	F kill	F kill Mdeg	F kill	F&P kill	F kill P cas	F kill
	M deg	K kill	M kill	F kill Mdeg	M kill	M&F deg	Mdeg P kill	Mdeg P cas	M deg
	F deg	K kill	M kill Fdeg	F kill	M&F deg	F kill	PKill Fdeg	P cas Fdeg	F deg
	P kill	K kill	M&P kill	F&P kill	Mdeg P kill	Fdeg Pkill	P kill	P kill	P kill
	P cas	K kill	M kill P cas	F kill P cas	Mdeg P cas	Fdeg P cas	P kill	P kill	P cas
	No effect	K kill	M kill	F kill	M deg	F deg	P kill	P cas	No effect

41. The process must be repeated for the exposed turret of the IFV when the vehicle is in partial defilade. Here the spaces for the BMP 1 result in the following percentage of turret volume:

a. Crew Space 53%; and

c. Weapon & Sensor Space 47%.

42. The weapon effects on the spaces and the actions resulting from the effects remain the same as for the entire vehicle. What changes are the proportions and the likelihood of damage resulting from penetration. Now the BMP 1 is unique in several ways. The ammunition is stored almost completely below the turret ring, and the turret is manned only by a gunner. The gunner is very low in the turret when engaging targets. In this vehicle killing or wounding the gunner is likely to result in an F kill.

TABLE XX
PROBABILITY OF IFV TURRET DAMAGE

SPACE	PROBABILITY				
	Destruction	Status	Damage	Status	No Effect
Crew	.45	F kill	.45	F kill	.10
Weapon & Sensor	.75	F kill	.20	Fdeg	.05

43. The likelihood of specific classes of damage can now be determined as follows:

TABLE XXI
PROBABILITY OF OUTCOME GIVEN IFV TURRET PENETRATION

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	53	.45	F kill	.239	.45	F kill	.239	.10	.052
Weapon & Sensor	47	.75	F kill	.353	.20	Fdeg	.094	.05	.023

44. Grouping of the classes of damage for a single penetration of a space from a single random number draw results in the following:

TABLE XXII
PROBABILITY OF IFV TURRET DAMAGE

Damage Result	% Probability
F kill	.831
Fdeg	.094
No Effect	.075

45. The methodology for an additional random number draw must be followed for the damage caused by the additional space involvement. This will produce a damage matrix which is much different from the tank and is as shown below.

TABLE XXIII
DAMAGE MATRIX FOR IFV TURRET TWO-SPACE INVOLVEMENT

		FIRST RANDOM NUMBER DRAW			
		K kill	F kill	F deg	No effect
SECOND RANDOM DRAW	K kill	K kill	K kill	K kill	K kill
	F kill	K killL	F kill	F kill	F kill
	F deg	K kill	F kill	F kill	F deg
	No effect	K kill	F kill	F deg	No effect

IV. APPLICATION TO COMMON VEHICLE TYPES

46. Recent use of the Janus simulation in DOR(J&L) has involved a limited number of armoured fighting vehicles. A survey was made of past games and it was determined that nine representative vehicles should be examined to initially establish the multiple kills methodology. Each of these vehicles represents either a unique type of vehicle or a typical vehicle that could be used to represent other similar vehicles. Acquiring information about the internal layout of the vehicles was time consuming and the results vary in accuracy. At best, the internal volumes are representative approximations which resulted from measuring sketches of the internal components drawn on three-view scale outlines. To determine the measurements more accurately would involve acquisition of engineering drawings, which in most cases would be impossible. Alternatively, measurements could be made from real vehicles, if they were available. If serious doubt exists about the spaces then one of these methods must be pursued. For this demonstration of the methodology, the technique used was adequate. As will be shown, it resulted in some surprising similarities.

47. All the vehicles chosen for investigation are fighting vehicles and frequently subject to direct fire engagements. Other vehicles involved in recent simulations have only been engaged infrequently or on the periphery of the scenario. These would be either SP artillery or logistics vehicles. The representative vehicles selected are listed below.

a. Leopard C1. This was the MBT commonly used as the armoured manoeuvre element in simulations. It will be displaced by the C2 variant but the numbers obtained here are applicable to that option as well. The Leopard has a typical internal layout for a tank with a four-man crew where the ammunition is stowed below the turret ring. The numbers obtained here would be applicable to any similar layout including the proposed new Armoured Combat Vehicle (ACV). The Leopard C1 data is found in Annex A.

b. T-72. This was chosen to represent all MBTs with three-man crews employing autoloaders. Consequently the figures obtained are applicable

to all models of the T-72, T-64, T-80 and T-90. The crew positions are extremely confining resulting in a reduced volume for crew space, but increased likelihood of destruction or damage. The data obtained for this vehicle is in Annex B.

c. M1A1. This MBT represents a unique layout in that it has a four-man crew like the Leopard, but all the ammunition is stored above the turret ring in specially engineered stowage that reduces the likelihood of catastrophic damage. This vehicle has uncharacteristically roomy crew stations. Annex C contains the data obtained for the M1A1.

d. BMP-1. The BMP-1 is unique in that it is an infantry fighting vehicle with a one-man turret and employs an autoloader. It has a very cramped interior. For our purposes it was considered to have a two-man crew, driver and gunner, with the crew commander and up to eight infantry as passengers. The BMP-1 exists in many variants and the data in Annex D can be used for all.

e. BMP-2. The BMP-2 has a more conventional two-man turret with a belt-fed cannon. The crew commander is considered part of the crew and not a passenger. There are seven passengers and all crew and passenger spaces are very cramped. The data for the BMP-2 is found in Annex E.

f. BRDM-S. This vehicle is normally referred to as BRDM-2 with AT-5 Spandrel. It is the anti-tank version of the BRDM-2 reconnaissance vehicle and has no conventional turret, just a retractable missile launcher. It has an autoloader system with two additional reloads stored in the vehicle hull. For the methodology used here, the missile launcher and the gunner's sight were considered as a turret for partial defilade calculations. The vehicle has a two-man crew, driver and crew commander/gunner. It is a roomy vehicle by Russian standards and contains empty spaces for floatation purposes. The BRDM-S data is contained in Annex F.

g. M113A3. The M113 is unique in that it is only an armoured personnel carrier and not an armoured fighting vehicle. It is a simple tracked box for

carrying infantry. It has no real turret, only a pintle mounted heavy machine gun. For this methodology, a notional short cylindrical turret was presumed to exist. The crew was considered to consist of the crew commander/gunner and the driver. The vehicle data found in Annex G can be used for all passenger-carrying variants of the M113.

h. Coyote. This vehicle is unique in that it is an eight-wheeled reconnaissance vehicle with a crew of four and a two-man turret. There is a larger proportion of equipment space as much is devoted to the surveillance suite. The crew positions are roomy compared to the Russian vehicles. Data for the Coyote is found in Annex H.

i. LAV III. The LAV III is similar in layout to the Coyote, but it has a crew of three and can carry up to eight passengers. LAV III data is found in Annex I.

48. The vehicles chosen for this paper are diverse. They represent the full range of armoured fighting vehicles. When the internal spaces were measured and tallied the relative sizes of the seven spaces were consistent with the differences between the vehicles. The table below summarizes the volumes obtained for the nine vehicles.

TABLE XXIV
FULLY EXPOSED AFV INTERNAL SPACES AS PERCENT OF VOLUME

INTERNAL SPACES	ARMOURED VEHICLES-FULLY EXPOSED % VOLUME								
	LEO C1	T-72	M1A1	BMP-1	BMP-2	BRDM-S	M113A3	Coyote	LAV III
Crew	23	19.1	19.9	9.7	17.6	20	11.8	31.7	12.7
Passenger	0	0	0	26.7	20.9	0	37.0	0	32.9
Drive Train	45.7	45.8	38.4	45.4	45	60	35.1	44.9	35.5
Ammunition	7.4	18.4	10.2	5.2	5.4	4.7	5.2	5.2	5.8
Fuel	6	2	9	3.7	3.7	2.3	3.4	5.8	6.8
Equipment	4.1	4	6.6	3.2	3.1	2.5	2.1	8.2	3.7
Weapon & Sensor	13.8	10.7	15.7	6.1	4.3	10.5	5.3	4.3	2.6

49. Considering the vehicles in partial defilade, the enclosed volumes were measured as follows:

TABLE XXV

PARTIAL DEFILADE AFV INTERNAL SPACES AS PERCENT OF VOLUME

INTERNAL SPACES	ARMOURED VEHICLES - PARTIAL DEFILADE % VOLUME								
	LEO C1	T-72	M1A1	BMP-1	BMP-2	BRDM-S	M113A3	Coyote	LAV III
Crew	30.6	45.9	24.5	53.3	53.6	0	49.8	47.7	47.7
Ammunition	10.3	0	37.8	0	0	40	0.3	0	0
Equipment	18.4	4.5	6	0	16.7	0	0	13	13
Weapon & Sensor	40.7	49.6	31.7	46.7	29.7	60	49.9	39.3	39.3

50. Once the volumes had been determined for each vehicle, the probability of damage could be determined using knowledge of the individual vehicle and applying the criteria for classification of damage. The calculations for individual vehicles are listed in the Annexes. A summary of probability of damage for the vehicles is shown in the tables below, grouped by vehicle type and showing the simple average probability for each damage level. What was surprising was the similarities between the probabilities for the different vehicles within a type classification.

TABLE XXVI
FULLY EXPOSED AFVs BY PROBABILITY OF DAMAGE

VEHICLE Tanks	K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
Leo C1	.09	.29	.08	.27	.16	0	0	.11
M1A1	.07	.26	.10	.25	.21	0	0	.11
Coyote	.07	.27	.03	.35	.17	0	0	.11
Western Tank Average	**.08**	**.27**	**.07**	**.29**	**.18**	**0**	**0**	**.11**
T-72	.17	.26	.08	.25	.16	0	0	.08
BRDM-S	.06	.31	.08	.31	.12	0	0	.12
APC/IFVs								
LAV III	.08	.14	.02	.27	.09	.10	.20	.10
BMP-1	.06	.24	.05	.25	.07	.12	.12	.09
BMP-2	.06	.25	.03	.25	.14	.09	.09	.09
M113A3	.06	.20	.03	.19	.08	.17	.17	.10
APC/IFV Average	**.07**	**.21**	**.03**	**.24**	**.09**	**.12**	**.14**	**.10**

51. For vehicles in partial defilade, the probability similarities are even more apparent.

TABLE XXVII
PARTIAL DEFILADE AFVs BY PROBABILITY OF DAMAGE

VEHICLE Tanks	K kill	M kill	F kill	Mdeg	Fdeg	No Effect
Leo C1	.07	.21	.24	.08	.29	.11
M1A1	.08	.12	.19	.03	.49	.09
Coyote	.00	.25	.24	.06	.33	.12
Western Tank Average	**.05**	**.19**	**.22**	**.06**	**.37**	**.11**
T-72	0	.16	.37	.02	.40	.05
BRDM-S	.30	0	.45	0	.20	.05
APC/IFVs						
LAV III	0	.20	.24	.06	.38	.12
BMP-1	0	.24	.35	.00	.33	.08
BMP-2	0	.24	.18	.07	.44	.07
M113A3	0	.22	.30	.00	.38	.10
APC/IFV Average	**0**	**.23**	**.27**	**.03**	**.38**	**.09**

52. The nine vehicles represent a small sample of armoured fighting vehicles but even with the approximations introduced in determining the internal spaces, the similarities of the probability of various types of damage appear to be consistent for vehicle types. Obviously the numbers would be refined with a more exact determination of internal layout. Also, the criteria for classification of damage should be raised from professional judgement to results of observations and studies. It would appear, however, that for operational research a set of probabilities based on a classification of vehicle type might be sufficient.

JANUS MULTIPLE KILL CATEGORY (MKC)

53. Janus 7.06D considers four types of vehicle kills; mobility (M), firepower (F), mobility and firepower (MF), and catastrophic (K). Each kill results in the complete loss of the specified capability and in the case of a K kill, the loss of the vehicle itself. An M kill results in a vehicle that can still fire but cannot move. An F kill results in a vehicle that is still mobile but cannot detect or engage enemy targets, while an MF kill combines the effects of an M and an F kill. The lost capability is considered to be repairable given the appropriate time, personnel, and equipment. Minor damage is considered crew repairable while more serious damage requires the attention of a repair echelon and possibly a recovery vehicle. Janus uses its PH and PK data sets to determine the category of kill and a new set of data called the Direct Fire Kill distribution is used to determine if the cause of the kill was due to mechanical damage, crew casualties or both. The Direct Fire Kill distribution is a function of the category of kill and the target system's Artillery Vulnerability Category. For any vehicle type listed in the Artillery Vulnerability Category, each category of kill (M, F, and MF) is broken down into cause, which must be mechanical damage, crew casualty or a combination of both.

54. Janus does not allow a vehicle to continue in action with some level of degraded capability caused by battle damage. The vehicle either has the capability or it does not. This means that a wide range of circumstances that could exist where battle damage would allow continuation with a mission at less than 100% capability are not modelled. For instance, battle damage to the primary gun sight or turret traverse mechanism would cause a reduction in capability but not prevent a tank from continuing in action using a secondary sight or manual traverse. Similarly, a crew casualty in battle may initially force a vehicle to halt but depending on the severity may permit it to carry on with a substitute driver or other crew member. The vehicle would acquire and engage targets less effectively as a turret position would be unmanned, but the vehicle could still engage enemy targets.

55. The methodology adopted by Janus is not as flexible or as realistic as the one described in this report. However, to implement the proposed methodology in Janus will require code modifications. Therefore, it is proposed that the Janus code be studied to

determine the amount of effort required to implement such a methodology. If implementation within Janus is unfeasible without substantial code modifications, it is suggested that the proposed methodology be examined to determine if it could be modified to produce the data required by Janus to use its MKC methodology.

V. CONCLUSIONS

56. In summary, a methodology has been developed to determine the outcome of a direct fire engagement in terms of damage assessment. The methodology is based on probabilities of damage caused to key vehicle spaces penetrated by a projectile. The methodology is somewhat subjective in that expert opinion was used to assign damage probabilities, but it is flexible and could easily be modified if empirical data became available. When the methodology was applied to vehicles used in previous Janus simulations, it revealed that classes of vehicles with similar characteristics have similar probabilities of damage. This could significantly reduce the data requirements for a simulation. The proposed vehicle classes and corresponding damage probabilities are:

a. Western Tanks. This class would consist of all four-man crewed AFVs and include reconnaissance vehicles with four-man crews, and SP artillery;

TABLE XXVIII
WESTERN TANK SINGLE SPACE PROBABILITY OF DAMAGE

Target Aspect	K kill	M kill	F kill	Mdeg	Fdeg	No Effect
Fully Exposed	.08	.27	.07	.29	.18	.11
Partial Defilade	.05	.19	.22	.06	.37	.11

b. Eastern Tanks. This class would justify the differences encountered with AFVs employing three-man crews and autoloaders;

TABLE XXIX
EASTERN TANK SINGLE SPACE PROBABILITY OF DAMAGE

Target Aspect	K kill	M kill	F kill	Mdeg	Fdeg	No Effect
Fully Exposed	.17	.26	.08	.25	.16	.08
Partial Defilade	.00	.16	.37	.02	.40	.05

c. APCs and IFVs. A single set of probabilities would be appropriate for all types of passenger carrying armoured vehicles;

TABLE XXX
APC/IFV SINGLE SPACE PROBABLITY OF DAMAGE

Target Aspect	K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
Fully Exposed	.07	.21	.03	.24	.09	.12	.14	.10
Partial Defilade	.00	.23	.27	.03	.38	.00	.00	.09

d. Anti-Tank Vehicles.

TABLE XXXI
ANTI-TANK SINGLE SPACE PROBABILITY OF DAMAGE

Target Aspect	K kill	M kill	F kill	Mdeg	Fdeg	No Effect
Fully Exposed	.06	.31	.08	.31	.12	.12
Partial Defilade	.30	.00	.45	.00	.20	.05

57. The methodology is not directly transferable to the current version of Janus. It is recommended that the Janus code be studied to determine the best implementation strategy.

VI. REFERENCES

1. I.F.B. Tytler, N.H. Thompson, B.E. Jones, P.J.H. Wormell, and C.E.S. Ryley, Brassey's Battlefield Weapons Systems & Technology Series – Volume I: Vehicles and Bridging, Brassey's Defence Publishers, London, 1985.

ANNEX A
DOR (J&L) RESEARCH NOTE RN 2000/08
APRIL 2000

LEOPARD C1 DATA

TABLE A-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION-EXPOSED LEOPARD C1

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	23	.40	M kill	.092	.45	Fdeg	.104	.15	.034
Passenger	0	0			0			0	
Drive Train	45.7	.40	M kill	.183	.50	Mdeg	.228	.10	.046
Ammunition	7.4	.70	K kill	.052	.25	Fdeg	.018	.05	.004
Fuel	6	.60	K kill	.036	.30	Mdeg	.018	.10	.006
Equipment	4.1	.45	M kill	.019	.45	Mdeg	.019	.10	.003
Weapon & Sensor	13.8	.60	F kill	.083	.30	Fdeg	.041	.10	.014

TABLE A-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE-EXPOSED-LEOPARD C1

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.088	.294	.083	.265	.163	.107

TABLE A-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE LEOPARD

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	30.6	.40	M kill	.122	.45	Fdeg	.138	.15	.046
Ammunition	10.3	.70	K kill	.072	.25	Fdeg	.026	.05	.005
Equipment	18.4	.45	M kill	.083	.45	Mdeg	.083	.10	.018
Weapon & Sensor	40.7	.60	F kill	.244	.30	Fdeg	.122	.10	.041

TABLE A-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE PARTIAL DEFILADE-LEOPARD C1

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.072	.205	.244	.083	.286	.110

ANNEX B
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T-72 DATA

TABLE B-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION-EXPOSED T-72

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	19.1	.30	M kill	.057	.65	Fdeg	.124	.05	.010
Passenger	0	0			0			0	
Drive Train	45.8	.40	M kill	.183	.50	Mdeg	.229	.10	.046
Ammunition	18.4	.85	K kill	.157	.10	Fdeg	.018	.05	.009
Fuel	2	.40	K kill	.008	.40	Mdeg	.008	.20	.004
Equipment	4	.45	M kill	.018	.45	Mdeg	.018	.10	.004
Weapon & Sensor	10.7	.75	F kill	.080	.20	Fdeg	.022	.05	.005

TABLE B-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE-EXPOSED-T-72

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.165	.258	.080	.255	.164	.078

TABLE B-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE T-72

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	45.9	.30	M kill	.138	.65	Fdeg	.298	.05	.023
Ammunition	0								
Equipment	4.5	.45	M kill	.020	.45	Mdeg	.020	.10	.005
Weapon & Sensor	49.6	.75	F kill	.372	.20	Fdeg	.099	.05	.025

TABLE B-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE-PARTIAL DEFILADE-T-72

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.158	.372	.020	.397	.053

ANNEX C
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M1A1 DATA

TABLE C-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION-EXPOSED M1A1

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	19.9	.40	M kill	.079	.45	Fdeg	.090	.15	.030
Passenger	0	0			0			0	
Drive Train	38.6	.40	M kill	.154	.50	Mdeg	.193	.10	.039
Ammunition	10.2	.20	K kill	.020	.75	Fdeg	.077	.05	.005
Fuel	9	.60	K kill	.054	.30	Mdeg	.027	.10	.009
Equipment	6.6	.45	M kill	.030	.45	Mdeg	.030	.10	.006
Weapon & Sensor	15.7	.60	F kill	.094	.30	Fdeg	.047	.10	.016

TABLE C-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE-EXPOSED M1A1

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.074	.263	.094	.250	.214	.105

TABLE C-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-M1A1

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	24.5	.40	M kill	.098	.45	Fdeg	.110	.15	.037
Ammunition	37.8	.20	K kill	.076	.75	Fdeg	.283	.05	.019
Equipment	6	.45	M kill	.027	.45	Mdeg	.027	.10	.006
Weapon & Sensor	31.7	.60	F kill	.190	.30	Fdeg	.095	.10	.032

TABLE C-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-M1A1

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.076	.125	.190	.027	.488	.094

ANNEX D
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BMP-1 DATA

TABLE D-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED BMP-1

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	9.7	.45	M kill	.044	.45	Fdeg	.044	.10	.010
Passenger	26.7	.45	P kill	.120	.45	P cas	.120	.10	.027
Drive Train	45.4	.40	M kill	.182	.50	Mdeg	.227	.10	.045
Ammunition	5.2	.75	K kill	.039	.20	Fdeg	.010	.05	.003
Fuel	3.7	.60	K kill	.022	.30	Mdeg	.011	.10	.004
Equipment	3.2	.45	M kill	.014	.45	Mdeg	.014	.10	.003
Weapon & Sensor	6.1	.75	F kill	.046	.20	Fdeg	.012	.05	.003

TABLE D-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- EXPOSED BMP-1

K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
.061	.240	.046	.252	.066	.120	.120	.095

TABLE D-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-BMP-1

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	53.3	.45	M kill	.240	.45	Fdeg	.240	.10	.053
Ammunition	0								
Equipment	0								
Weapon & Sensor	46.7	.75	F kill	.350	.20	Fdeg	.093	.05	.023

TABLE C-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE PARTIAL DEFILADE-BMP-1

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.240	.350	0	.330	.080

ANNEX E
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BMP-2 DATA

TABLE E-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED BMP-2

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	17.6	.30	M kill	.053	.65	Fdeg	.114	.05	.009
Passenger	20.9	.45	P kill	.094	.45	P cas	.094	.10	.021
Drive Train	45	.40	M kill	.180	.50	Mdeg	.225	.10	.045
Ammunition	5.4	.75	K kill	.041	.20	Fdeg	.011	.05	.002
Fuel	3.7	.60	K kill	.022	.30	Mdeg	.011	.10	.004
Equipment	3.1	.45	M kill	.014	.45	Mdeg	.014	.10	.003
Weapon & Sensor	4.3	.60	F kill	.026	.30	Fdeg	.013	.10	.004

TABLE E-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE-EXPOSED BMP-2

K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
.063	.247	.026	.250	.138	.094	.094	.088

TABLE E-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-BMP-2

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	53.6	.30	M kill	.161	.65	Fdeg	.348	.05	.027
Ammunition	0								
Equipment	16.7	.45	M kill	.075	.45	Mdeg	.075	.10	.017
Weapon & Sensor	29.7	.60	F kill	.178	.30	Fdeg	.089	.10	.030

TABLE E-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-BMP-2

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.236	.178	.075	.437	.074

ANNEX F
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BRDM-S DATA

TABLE F-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED BRDM-S

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	20	.45	M kill	.090	.45	Fdeg	.090	.10	.020
Passenger	0								
Drive Train	60	.35	M kill	.210	.50	Mdeg	.300	.15	.090
Ammunition	4.7	.75	K kill	.035	.20	Fdeg	.009	.05	.003
Fuel	2.3	.85	K kill	.020	.10	Mdeg	.002	.05	.001
Equipment	2.5	.45	M kill	.011	.45	Mdeg	.011	.10	.003
Weapon & Sensor	10.5	.75	F kill	.079	.20	Fdeg	.021	.05	.005

TABLE F-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- EXPOSED BRDM-S

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.055	.311	.079	.313	.120	.122

TABLE F-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-BRDM-S

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	0		M kill			Fdeg			
Ammunition	40	.75	K kill	.300	.20	Fdeg	.080	.05	.020
Equipment	0		M kill			Mdeg			
Weapon & Sensor	60	.75	F kill	.450	.20	Fdeg	.120	.05	.030

TABLE F-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-BRDM-S

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.300	0	.450	0	.200	.050

ANNEX G
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M113A3 DATA

TABLE G-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED M113A3

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	11.8	.45	M kill	.053	.45	Fdeg	.053	.10	.012
Passenger	37.0	.45	P kill	.167	.45	P cas	.167	.10	.037
Drive Train	35.2	.40	M kill	.141	.50	Mdeg	.176	.10	.035
Ammunition	5.2	.75	K kill	.039	.20	Fdeg	.010	.05	.003
Fuel	3.4	.60	K kill	.020	.30	Mdeg	.010	.10	.004
Equipment	2.1	.45	M kill	.009	.45	Mdeg	.009	.10	.003
Weapon & Sensor	5.3	.60	F kill	.032	.30	Fdeg	.016	.10	.005

TABLE G-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- EXPOSED M113A3

K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
.060	.200	.030	.190	.080	.170	.170	.100

TABLE G-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-M113A3

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	49.8	.45	M kill	.224	.45	Fdeg	.224	.10	.050
Ammunition	0.3	.75	K kill	.002	.20	Fdeg	.001	.05	0
Equipment	0	0	M kill	0	0	Mdeg	0	0	0
Weapon & Sensor	49.9	.60	F kill	.299	.30	Fdeg	.150	.10	.050

TABLE G-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-M113A3

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.220	.300	0	.380	.100

ANNEX H
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COYOTE DATA

TABLE H-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED COYOTE

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	31.6	.40	M kill	.126	.45	Fdeg	.142	.15	.048
Passenger	0	0			0			0	
Drive Train	44.9	.25	M kill	.112	.65	Mdeg	.292	.10	.045
Ammunition	5.2	.75	K kill	.039	.20	Fdeg	.010	.05	.003
Fuel	5.8	.60	K kill	.035	.30	Mdeg	.017	.10	.006
Equipment	8.2	.45	M kill	.037	.45	Mdeg	.037	.10	.008
Weapon & Sensor	4.3	.60	F kill	.026	.30	Fdeg	.013	.10	.004

TABLE H-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- EXPOSED COYOTE

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
.074	.275	.026	.346	.165	.114

TABLE H-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- PARTIAL DEFILADE-COYOTE

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	47.7	.40	M kill	.191	.45	Fdeg	.215	.15	.071
Ammunition	0	0	K kill	0	0	Fdeg	0	0	0
Equipment	13	.45	M kill	.059	.45	Mdeg	.059	.10	.012
Weapon & Sensor	39.3	.60	F kill	.236	.30	Fdeg	.118	.10	.039

TABLE H-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-COYOTE

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.250	.236	.059	.333	.122

ANNEX I
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LAV III DATA

TABLE I-I
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION- EXPOSED LAV III

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	12.7	.30	M kill	.038	.55	Fdeg	.070	.15	.019
Passenger	32.9	.30	P kill	.099	.60	P cas	.197	.10	.033
Drive Train	35.5	.25	M kill	.089	.65	Mdeg	.231	.10	.035
Ammunition	5.8	.75	K kill	.044	.20	Fdeg	.012	.05	.002
Fuel	6.8	.60	K kill	.041	.30	Mdeg	.020	.10	.007
Equipment	3.7	.45	M kill	.017	.45	Mdeg	.017	.10	.003
Weapon & Sensor	2.6	.60	F kill	.016	.30	Fdeg	.008	.10	.002

TABLE I-II
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- EXPOSED LAV III

K kill	M kill	F kill	Mdeg	Fdeg	P kill	P cas	No Effect
.080	.140	.020	.270	.090	.100	.200	.100

TABLE I-III
PROBABILITY OF OUTCOME SINGLE SPACE PENETRATION-PARTIAL DEFILADE-LAV III

SPACE	% Vol	PROBABILITY							
		Destruction	Status	prob	Damage	Status	prob	No Effect	prob
Crew	47.7	.30	M kill	.143	.55	Fdeg	.262	.15	.072
Ammunition	0	.20	K kill	0	.75	Fdeg	0	.05	0
Equipment	13	.45	M kill	.059	.45	Mdeg	.059	.10	.012
Weapon & Sensor	39.3	.60	F kill	.236	.30	Fdeg	.118	.10	.039

TABLE I-IV
PROBABILITY OF DAMAGE TYPE-SINGLE SPACE- PARTIAL DEFILADE-LAV III

K kill	M kill	F kill	Mdeg	Fdeg	No Effect
0	.202	.236	.059	.380	.123

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This paper proposes an operational research methodology for determining the effects on an armoured vehicle, its crew and passengers of an armour-piercing projectile which has defeated the protection of the vehicle. The process involves determining the proportion of the internal volume occupied by key spaces. The effect on the vehicle is estimated for a range of damage to each space. The probability of damage to the vehicle is determined by the proportion of the volume and the likelihood of damage represented by the spaces that the projectile penetrates. Application of the process to representative vehicles demonstrates that a consistency exists for similar types of vehicles.

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Armoured Vehicle